ENERGY PERFORMANCE AND GREENHOUSE EFFECT OF BIOFUELS

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Abstract

The French Agency for Environment and Energy Control (ADEME) and the Management for Energy and Mineral Resources (DIREM) decided in 2002 to launch a study to establish the balance of different types of biofuels in terms of energy performance and greenhouse effect. CETIOM, the French technical centre for oilseed crops was asked to take part in this study concerning the agricultural step of the production of vegetable oil methyl esters produced from winter oilseed rape and sunflower. For sunflower, the agricultural step represents about 50% of the total energy mobilization, with mechanization representing 70% of the energy consumed in agricultural production. The ratio of produced energy/nonrenewable energy mobilized is about 3 for methyl esters produced from sunflower and winter oilseed rape, compared to gas oil, the mineral fuel of reference, whose ratio is 0,917. The energy performance of ETBE (ethyl-tertiary-butyl-esters) produced from wheat and sugar beet is inferior. The reduction of emissions of greenhouse gases in equivalent CO2 generated by each biofuel is close: about 2.5 tons equivalent CO2 are economized for 1 ton of biofuel produced. The respective parts of CO2 and N2O in the greenhouse gas emissions are 80 and 17 for sunflower. Simulations have been made to take into account the probable technological developments by 2009. They show that about 7% of the effort of economy envisaged for France according to the protocol of Kyoto could be reached thanks to the production of ethanol and methyl esters.

Introduction

The European context of development of renewable energy and the project for a European Directive on biofuel must lead France, a country with an important agricultural dimension within Europe, to take an active part in the production and use of biofuels. The support and development of these biofuels requires a reliable and quantitative knowledge of their energy performances and greenhouse effect, which are their two strong points from an environmental point of view and in terms of energy independence. In this context, ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie) on one hand, and DIREM (Direction des Ressources Energétiques et Minérales) on the other hand, joined to produce energy and greenhouse effect balances, reliable and up-to-date, for the main biofuels produced and used in France: ethanol and ETBE (ethyl-tertiary-butyl-ester) produced from wheat or sugar beet, vegetable oils and VOME (Vegetable Oil Methyl Esters) produced from winter oilseed rape or sunflower, gasoline, MTBE (methyl-tertiary-butyl-ester) and gas oil. The study of the energy and greenhouse effect balance was carried out from January to July 2002. This paper describes the methodology used in this study, and gives the main results.

Materials and Methods

This work was entrusted to the Ecobilan company, a member of the Durable Department Development of the PricewaterhouseCoopers cabinet. The Ecobilan company historically has the longest expertise in life cycle analysis in France, and in addition completed many studies in the sectors of Agriculture and Energy. The balance has been produced by the method of life cycle analysis. Several works on energy analysis or life cycle analysis have already been undertaken on these types for more than 10 years and made it possible to produce information for the present study. However, these studies relate to one or the other of the types of biofuel, and correspond to an evaluation at a certain time of development of these products. Moreover, these studies were carried out independently, on the basis of assumption and methodological choice which can be different. So it was important to update and supplement the various data, but also to ensure comparable methodological choices between biofuels, in order to establish homogeneous energy balances. Moreover, the present study also proposes that assessments be brought up-to-date and adapted to the French case, using the same methodology of evaluation for biofuels and traditional fuels (gas oil and gasoline), in order to have a reliable comparison.

The main steps of the dies that have been taken into account to establish the balances are the following. For gasoline and gas oil: production of crude oil, transport of the crude, refining, and distribution from the refinery to the distributor. For biofuels: agricultural production, provisioning of the biofuel factories, industrial transformation and synthesis of the biofuels and transport to the distribution. In the agricultural production stage, primarily included are the synthesis of the inputs (fertilizers, pesticides) and the mechanization from soil preparation to harvest.

The sunflower crop management strategy used to calculate the balances has been proposed by CETIOM, the French technical center for oilseed crops. It was issued from questionnaries carried out every 2 years by CETIOM to discover the diversity and evolutions of sunflower crop management in France. An average crop management strategy was defined from the main regions of production of sunflower in France. This crop strategy is described as follows: tillage for soil preparation and residue degradation; the ratio of ploughing/no-tillage and low-tillage is 85/15 for the French sunflower areas (this ratio has been taken into account to calculate the balance); the average sowing density is 700,000 seeds/ha; harrowing on 40 percent of the surface; the total quantity of pesticides is 2.1 kg/ha, distributed as follows: 81% weedkillers, 14% insecticides and 5% fungicides; the quantity of fertilizer per hectare is 39 kg/ha nitrogen, 46 kg/ha phosphorus and 61 kg/ha potassium (this quantity of fertilizer has been undervalued to allow for the enrichment of the soil with phosphorus and potassium by burying of sunflower residues after harvest); and harvest; the mean yield used in this study is 2.4 tons/ha.

Results and Discussion

Figure 1 describes the energy mobilization for the crops used to produce biofuels, sunflower and winter oilseed rape, wheat and sugar beet. The total energy expressed in MegaJoules per hectare (MJ/ha) is distributed between the three main components of crop management: mechanization, pesticides and fertilizers. Producing one hectare of sunflower requires 10 620 MJ, which is much lower than the values obtained for the other crops. This is primarily explained by the smaller quantity of fertilizers used to produce sunflower seeds. Mechanization represents 70% of the energy used in the agricultural production step for sunflower. In considering the whole scheme of production, two main steps can be defined: the agricultural production step (from soil preparation to harvest of the crop), and the industrial step. The industrial processes are quite different for ETBE (ethyl-tertiary-butyl-ester) produced from wheat or sugar beet, and VOME (Vegetable Oil Methyl Esters) produced from rape or sunflower. This is shown in Figure 2. We can observe that the contributions of the agricultural and industrial steps to nonrenewable energy use are very different; for VOME, the agricultural step represents about 50% of the total mobilization, whereas it represents less than 5% for ETBE. This is linked to the fact that the industrial process for ETBE includes a step which uses a lot of nonrenewable energy.

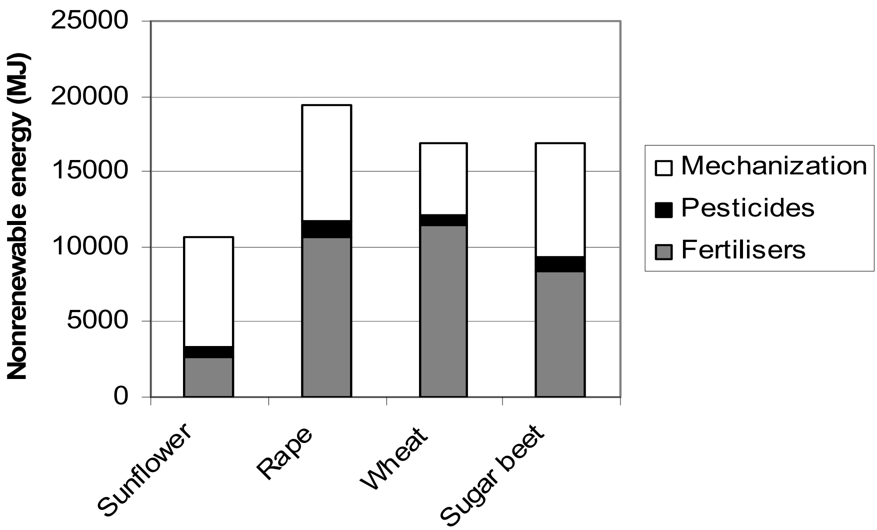

Figure 1. Energy mobilization of the various crops used for the production of biofuels (MegaJoules per hectare).

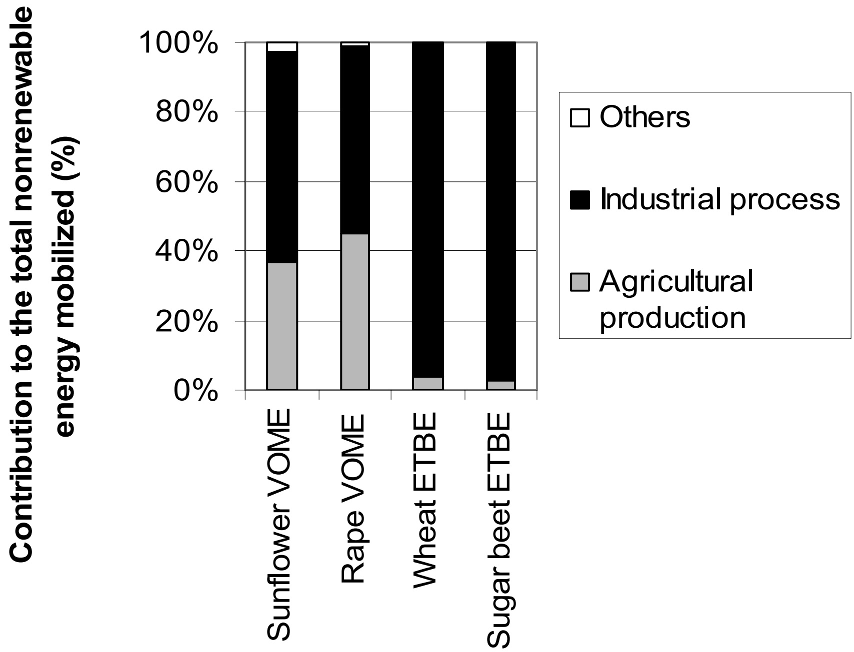

Figure 2. Contribution to the total nonrenewable energy mobilized of the different steps of the production of biofuels ("Others" includes primarily transport and distribution of the products).

To assess the performances of the different biofuels and to make a comparison, we used an indicator: the ratio of produced energy/nonrenewable energy mobilized. The energy mobilized includes consumption of primary energy and energy contained in the matter. The results (Table 1) show the good performance of production of ethanol with an energy efficiency of 2 compared to that of gasoline (0.873). Vegetable oil presents important yields from 4.7 to 5.5 and the methyl esters have a good yield close to 3, compared to gas oil (0.917). In other words, gas oil consumes a bit more energy than it produces, whereas methyl esters produced from rape and sunflower release about three times more energy than they consume in production.

Table 1. Energy balance of the complete biofuels in 2005.

Energetic balance	Gasoline (50 ppm S)	Wheat ethanol	Sugar beet ethanol	MTBE (1)	Wheat ETBE (2)	Sugar beet ETBE (2)
Ratio (4)	0.873	2.05	2.05	0.76	1.02	1.02
	Gas oil (50 ppm S)		Rape oil	Sunflower oil	Rape VOME (3)	Sunflower VOME (3)
Ratio (4)	0.917		4.68	5.48	2.99	3.16

(1) Methyl-Tertiary-Butyl-Ester; (2) Ethyl-Tertiary-Butyl-Ester; (3) Vegetable-Oil-Methyl-Esters;
(4) Ratio: Produced energy / Nonrenewable energy mobilized.

The difference between the mineral fuel of reference and its compatible vegetable substitute generates an energy profit and a profit for greenhouse gas for the whole. This profit can be expressed by the reduction of the emissions of greenhouse gases in equivalent CO2 per ton of biofuel. Ethanol is compared below with the gasoline and the esters are compared with gas oil (Table 2).

Table 2. Profit of the emissions of greenhouse gases for four types of biofuels.

	Versus	Teq CO2/t in 2005	Teq CO2/t in 2009
Sugarbeet ethanol	Gasoline	2.748	3.108
Wheat ethanol	Gasoline	2.728	3.130
Rape VOME	Gas oil	2.502	2.667
Sunflower VOME	Gas oil	2.645	2.783

The reduction of emissions of greenhouse gases in equivalent CO2 generated by each method are close: about 2.5 tons equivalent CO2 are economized for 1 ton of biofuel produced. The two main gases that contribute to greenhouse effect are CO2 and N2O, whose respective contributions are different for the different types of biofuels. N2O emissions have been assessed by applying a multiplicative factor to the quantity of nitrogen fertilizer received by each crop. The ratio CO2/N2O contribution is 80/17 for sunflower, and 62/35 for winter oilseed rape. For sunflower, this ratio is explained by the fact that fertilization contributes much less than mechanization to energy mobilization, and as a consequence N2O contribution linked to fertilization is low to compared to CO2 contribution, primarily linked to mechanization. The ratio is more balanced for winter oilseed rape. The very low contribution of N2O to greenhouse effect for sugar beet is explained by the organic form of nitrogen applied on the crop, which leads to lower N2O emissions than the mineral form. For sunflower, the agricultural production step represents 60% of the emissions of greenhouse gases; the remaining 40% come from the industrial process. This ratio is 71/39 for rape. As for energy mobilization, the industrial process represents the main part of the contribution to greenhouse gas emissions for ETBE: the ratio of Agricultural contribution and Industrial contribution is 15/85 for wheat and sugar beet ETBE.

Different prospective scenarios have been built. They take into account probable technological developments by 2009. For the agricultural production step, they include an improvement in yield, a progression of non-tillage, and an optimisation of practises of fertilization and crop protection. The results of these scenaros for greenhouse gas emissions are shown Table 2. The profits of the emissions of greenhouse gases are improved from 5 to 15% for the various biofuels between 2005 and 2009. The energy yield for sunflower methyl esters improved from 3.16 to 3.44. Taking into account the quantities of biofuels produced in 2001, that is to say 90,513 T of ethanol and 310,700 T of winter oilseed rape methyl ester, the profits for greenhouse gases represent 280,000 teq carbon avoided. In 2010, according to the assumptions selected, that is to say a production of 770,000 T of ethanol and 620,000 T of methyl ester, the profit for greenhouse gases represents 1,107,000 teq carbon avoided, maybe nearly 7 % of the effort of economy envisaged for France according to the protocol of Kyoto (16 MT Carbon).

Conclusions

Production of biofuels, ethanol or esters, generates a profit for the greenhouse effect compared to traditional fuels (gas oil, gasoline or natural gas). The profits are close for the different biofuels in terms of greenhouse effect, whereas methyl esters produced from winter oilseed rape and sunflower have much higher energy performances, producing three times more energy than they consume in production. The reliable and up-to-date results of this study will contribute to reflexion on the support and the development of biofuels in the European context of renewable energy and in the worldwide context of the fight against greenhouse effect put in concrete form with the protocol of Kyoto in 1997.

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